EPA's Reach Indexing Project - Using GIS to Improve Water Quality Assessment

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Abstract:

The Waterbody System, originally developed by the U.S. Environmental Protection Agency (EPA) to support preparation of the report to Congress required under Section 305(b) of the Clean Water Act, is a potentially significant source of information on the use support status and the causes and sources of impairment of waters of the United States. There is a growing demand for geographically referenced water quality assessment data for use in interagency data integration, joint analysis of environmental problems, establishing program priorities, and planning and management of water quality on an ecosystem or watershed basis.

Since location of the waterbody assessment units is the key to analyzing their spatial relationships, EPA has placed particular emphasis on anchoring waterbodies to the River Reach File (RF3). The Reach File provides a nationwide database of hydrologically linked stream reaches and unique reach identifiers, based on the 1:100,000 USGS hydrography layer.

EPA began the reach indexing project to provide an incentive for States to link their waterbodies to RF3 and to ensure increased consistency in the approaches employed in reach indexing. After a successful 1992 pilot effort in South Carolina, an expanded program began this year. Working with Virginia, a route system data model was developed and proved successful in conjunction with State use of PC Reach File (PCRF), a PC program for relating waterbodies to the reach file. Arc/Info provides an extensive set of commands and tools for development and analysis of route systems and use of dynamic segmentation. One important advantage of the route system is that it avoids the necessity of breaking arcs, an important consideration in using RF3 as the base coverage in a GIS. The use of dynamic segmentation to organize, display and analyze water quality assessment information also has the advantage of simplifying use of the existing waterbody system data. However, because of the variability in delineation of waterbodies, a number of other approaches had to be used in other States. Experience in working with these States defines a range of issues that must be addressed in developing a consistent set of locational features for geospatial analysis.

Wider use of these data is also dependant upon increased consistency in waterbody assessments within and between States. Attaining this consistency in assessment data is complicated by the choice of beneficial use as the base for assessment of water quality condition, the historical emphasis on providing flexible tools to States, and the lack of robust standards for assessment of water quality condition. Possible resolutions to the problem of building a national databases from data collected by independent entities are explored

I. Section 305(b) of the Clean Water Act and the Waterbody System

Section 305(b)

Since 1975, Section 305(b) of the Federal Water Pollution Act, commonly known as the Clean Water Act (CWA), has required states to submit a report on the quality of their waters to the Environmental Protection Agency (EPA) Administrator every two years. The Administrator is required to transmit these reports, along with an analysis of them, to the Congress.

State assessments are based on the extent to which the waters meet state water quality standards, as measured against the state's designated beneficial uses. For each use, the state establishes a set of water quality criteria or requirements that must be met if the use is to be realized. The CWA provides the primary authority to states in setting their own standards but requires that all state beneficial uses and their criteria comply with the 'fishable and swimmable' goals of the Act.

Assessments and the Role of Guidelines

EPA issues guidelines to coordinate state assessments, to standardize assessment methods and terminology, and to encourage states to assess support of specific beneficial uses (e.g., aquatic life support, drinking water supply, primary contact recreation, fish consumption). For each use, EPA asks that the state categorize its assessment of use support into five classes:

- fully supporting - meets designated use criteria
- threatened - may not support uses in the future unless action is taken
- partially supporting - fails to meet designated use criteria at times
- not supporting - frequently fails to meet designated use criteria
- not attainable - use support not achievable

The preferred assessment method is for the state to compare monitoring data with numeric criteria for each designated use. However, if monitoring data are not available, states may use qualitative information to determine use support levels.

In cases where use support is impaired (partially or not supporting), the states list the sources (e.g., municipal point source, agriculture, combined sewer overflows) and causes (e.g., nutrients, pesticides, metals) of the use support problems. Not all impaired waters are characterized. Determining specific sources and causes requires data that is frequently not available.

States generally do not assess all of their waters each biennium. Most states assess a subset of their total waters every two years and this subset is frequently determined by the state's perception of its greatest water quality problems. To this extent, assessments are skewed toward waters with the most pollution and may, if viewed as representative of overall water quality, overstate pollution problems.

Assessment data characteristics

Use support is determined by each state for its own set of beneficial uses. Despite EPA's encouragement of standardized use categories, the wide variation in state designated beneficial uses makes comparability of state uses an inherent problem. This affects the validity of aggregation and use of data across state boundaries. Comparable categorization of waters into use support categories is also problematic; the qualitative criteria for use support levels have been applied in very different ways in different states. A further limitation on utility of 305(b) data is that data are aggregated at the state level and questions about the use support status of individual streams cannot be resolved without additional information. While some states report on individual waters in their 305(b) reports), EPA's Waterbody System is the primary database for assessment information on specific waters.

State monitoring and assessment activities are also highly variable. Assessments are based on monitoring data or more subjectiveevaluation. The evaluation category, in particular differs among states.

Waterbody System

The Waterbody System (WBS) is a database and a set of analytical tools for collecting, querying and reporting on state 305(b) information. It includes information on use support and the causes and sources of impairment for waterbodies, identification and locational information and a variety of other program status information.

As pointed out earlier, although some states discuss the status of specific waters in their 305(b) reports, many do not. The Waterbody System is generally much more specific than the 305(b) reports. It provides the basic assessment information needed to track the status of individual waters in time and, if georeferenced, to locate assessment information in space. By allowing the integration of water quality data with other related data, it provides a framework for improving assessments.

WBS has significant potential for management planning and priority setting and can serve as the foundation for watershed and ecosystem based analysis, planning and management. In this respect. it can play a vital role in setting up watershed based permitting of point sources. The primary function of WBS is in defining where our water quality problems do and do not exist.

WBS is increasingly finding a use in meeting the identification requirement for waters requiring a total maximum daily load allocation (TMDL). It can serve as the initial step in the detailed allocation analysis included in the TMDL process. WBS is an important component of EPA participation in joint studies and analyses. The Agency is currently participating with the Soil Conservation Service in a project to jointly identify waters that are impaired due to agricultural nonpoint source pollution. WBS can also be the foundation for efforts to provide improved public access at the State and national levels to information on the status of their waters.

One of the key things to recognize is that the Waterbody System is voluntary. Of the 54 states, territories, river basin commissions and Indian tribes that submitted 305(b) reports, approximately 30 used the waterbody system in the 1992 cycle. While submissions for the 1994 cycle are not complete, we anticipate about the same level of participation. This represents about a sixty percent rate of participation in WBS and this may be the limit for a voluntary system. This severely limits use of WBS assessment data for regional and national level analysis. If data at the national level is needed, mandatory data elements, formats and standards may be necessary. EPA is currently attempting to achieve consistency through agreement with other state and federal agencies. The recent work of the

Interagency Task Force on Monitoring offers hope that there will be eventual consensus on the need for nationally consistent assessment data and mutually agreed upon standards for collection, storage and transfer. Spatial data is already governed by the Spatial Data Transfer Standards which allow movement of data between dissimilar platforms. The Federal Geographic Data Committee is providing leadership in coalescing data integration at the Federal level; providing a model for government and private sector efforts. However, this level of cooperation has not always been present in water assessment data management. If consistency cannot be achieved through cooperative efforts, assuming that national and regional assessment data is needed, regulations may be needed. In the absence of a mutual commitment by EPA and the States to using common assessment standards, developing a national database may not be feasible.

WBS was originally developed as a dBase program in 1987. It has undergone several revisions since then and the current version 3.1 is written in Foxpro 2.0. The WBS software provides standard data entry, edit, query and report generation functionality. WBS has grown substantially in the years since its inception, primarily in response to the expressed needs of WBS users and EPA program offices. Parenthetically, it should be noted that the program's memory requirements and the size of the program and data files are of growing concern to state WBS users and the WBS program manager. Because of the wide range of WBS user capabilities and equipment, it is necessary to support an array of hardware from high capacity pentium computers to rudimentary 286 machines with 640 Kb of memory and small hard disks. This makes memory problems inevitable for some users.

While WBS contains over 208 fields, exclusive of those in lookup tables, the core data needed to comply with 305(b) requirements are found in approximately thirty fields in four files. These fields contain identification information for the waterbody, the date the assessment was completed, the status of use support for beneficial uses, and the causes and sources of any use impairment in the waterbody. The uses considered are both State designated uses and a set of nationally consistent uses (e.g. overall use, aquatic life support, recreation) specified in the 305(b) guidelines. The other essential piece of information is the geographic location of the waterbody. This is discussed in detail in the remainder of this paper..

There are significant differences in the analytical base as well as in assessments. EPA provided little initial guidance on defining waterbodies; therefore there is a wide variety of waterbody configurations among states. Waterbodies are supposed to represent waters of relatively homogeneous water quality conditions, but the interpretation of this guidance has resulted in major differences in Waterbody definition.

Initially, many states developed linear waterbodies and these were often very small. The large number of waterbodies that were delineated created significant difficulties in managing the assessment workload and were not ideal in the context of the growing need for watershed information. Some States, such as Ohio developed their own river mile systems.

As discussed below, some states indexed their waterbodies to earlier versions of the reach file and, therefore, the density of the streams included in these waterbodies is fairly sparse. Recently, many states have been redefining their waterbodies on the basis of small watersheds (SCS basins - either 11 digit or 14 digit HUCs).

Locating waterbodies geographically is a necessary prerequisite to assessing water quality on a watershed or ecosystem basis. The WBS has always included a number of locational fields, including: county name and FIPS, river basin, and ecoregion. However, these fields have not been uniformly populated. One of the WBS files includes fields for the RF3 reaches included in the Waterbody. However, while a few States had indexed their waterbodies to older versions of the Reach File (RF1 and

RF2), no State had indexed to RF3 until 1992.

In 1992, EPA initiated a demonstration of GIS technology, working in partnership with the South Carolina Department of Health and Environmental Control. This project involved indexing South Carolina's Waterbodies to RF3, developing a set of AML's for query and analysis, production of coverages of water quality monitoring stations and discharge points, and using GIS tools in exploring ways to improve water quality assessments. South Carolina has defined its Waterbodies as SCS basins.

The results have been very encouraging. First, South Carolina took the initial coverages and decided they needed much more specificity in their use support determinations and in their mapping of the causes and sources of impairment, so they mapped these features down to the reach level. Next, they decided that they needed better locational information, so they used Global Positioning Satellite receivers to identify accurate locations for discharges and monitoring stations. They then used GIS query and analysis techniques to relate their monitoring and discharge data to their water quality criteria. The State is using GIS to actively identify water quality problems and improve their assessments.

In 1993, EPA worked cooperatively with several states to index their Waterbodies to the Reach File. Virginia was the next state to be indexed and the state demonstrated the successful use of PCRF software, described later in this paper, for indexing waterbodies to the reach file. Ohio and Kansas are essentially complete. Each of these states required a somewhat different approach than Virginia. These differences are discussed later, but it is important to recognize the need for flexibility in dealing with states on reach indexing issues. There often is a considerable investment in existing Waterbody delineations. It is important that EPA provide the capability to link the state's existing assessment data to the reach file in order to get state buy in.

The results of Ohio's indexing of a typical Cataloging Unit are shown in Figure 1. Part of the output of the Kansas work is shown in Figure 2. We can link attribute use support, cause and source data to each of these waterbodies now. In the future, we hope to map these attributes at a higher level of resolution - down to the reach segment level. GIS has proven to be a useful assessment tool. With higher resolution, it should prove to be even more useful in identifying water quality problems, picking up data anomalies, and assessing management actions, strategies, and policies. We have learned much in the process and our enthusiasm for place based management is stronger than ever.

II. The Reach Indexing Project - Georeferencing the Waterbody System

The Purpose of Reach Indexing:

The Reach Indexing Project is designed to locate waterbodies using RF3 as an electronic basemap of hydrography and to code RF3 reaches with the specific waterbody identifier. Once waterbodies are linked to their spatial representation, they can be queried and displayed with assessment data located in WBS files.

Overview :

Reach indexing includes several steps. First, the state must supply waterbody locations and WBIDs. Next a set of procedures must be developed for indexing. Finally, the coded RF3 data must be produced.

Input data to the indexing process includes:

- A list of valid waterbody identifiers (WBIDs). In most cases, these identification numbers have already been input to the WBS by the State.
- Information about the location of each waterbody. Locational information may come in the form of marked up paper maps showing waterbody locations, electronic files from WBS containing waterbody indexing expressions (discussed later), or it may be embedded in the WBID itself.
- A complete set of RF3 data for the state being indexed.

Procedures used to index waterbodies can be almost fully automated, semi-automated, or completely manual, depending on the type of information supplied by the state.

The final result of the indexing processes is a set of RF3 coverages which contain a waterbody identifier (WBID) attribute. With this product, assessment data collected and stored by waterbody can be queried and displayed in a GIS environment.

The Reach File Database

The Reach File is a hydrographic database of the surface waters of the continental United States. Elements within the database represent stream segments. The elements were created for several purposes:

- To perform hydrologic routing for modeling programs,
- To identify upstream and downstream connectivity, and
- To provide a method to uniquely identify any particular point associated with surface waters.

The unique reach identifier has been used to associate other EPA national databases, such as STORET, to surface waters. Any point within these databases can be associated with, and identified by, a specific location on any surface water element, such as a reservoir, lake, stream, wide river, or coastline.

There are three versions of the Reach File. The first, created in 1982, contained 68,000 reaches; the second, released in 1988, doubled the size of version 1; the third version (RF3) has over 3,000,000 individual reach components.

The base geography of RF3 is derived from USGS hydrographic data (1:100,000 scale) stored in DLG format. Unlike DLG data, which is partitioned by quad sheet boundaries, RF3 data is partitioned by USGS Cataloging Units (CU). A Cataloging Unit is a geographic area representing part or all of a surface drainage basin, a combination of drainage basins, or a distinct hydrologic feature. They are used by USGS for cataloging and indexing water-data acquisition activities.

There are over 2,100 Cataloging Units in the continental United States. CUs are fairly small; for example, 45 units fall partially or completely within the state of Virginia. (Figure 3.)

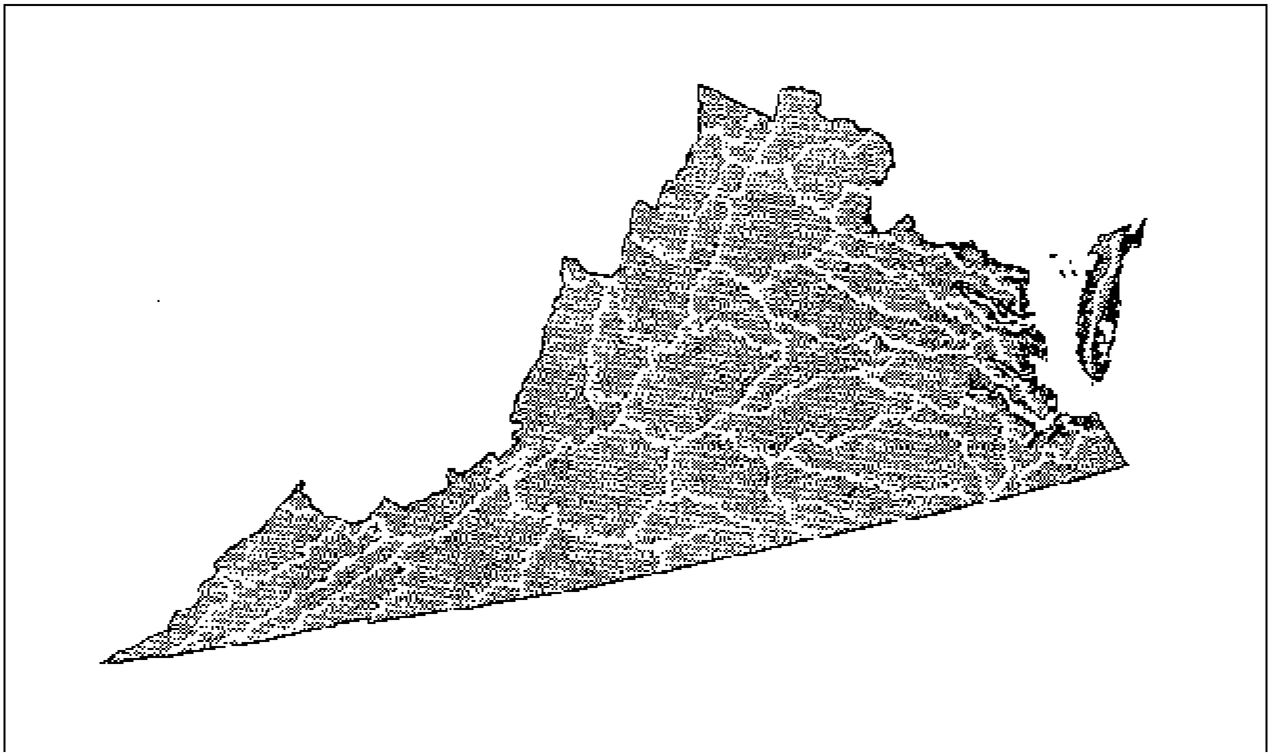

Figure 3. Cataloging Units in Virginia

RF3 is a powerful data source used in hydrologic applications for many reasons, including the following:

- RF3 has spatial network connectivity used by topological upstream/downstream modeling tools;
- It has attributes that describe connectivity, which means that upstream/downstream navigation can also be accomplished analytically (without topological networking);
- RF3 has a simple and consistent unique numbering system for every stream reach in the United States; and
- RF3 has built-in river mileage attributes that describe upstream/downstream distances along river reaches.

Use of RF3 in the Indexing Process

When importing Reach File data from EPA's mainframe computer, an Arc Attribute Table (AAT) is automatically built for each RF3 coverage. The AAT contains the standard AAT fields, plus these additional items:

12070104-ID	CU	SEG	MI	UP	DOWN
1	12070104	1	0.00	-1	0
2	12070104	1	1.30	-1	0
3	12070104	1	2.10	-1	0

4	12070104 2	0.00 -1	0
5	12070104 3	0.00 -1	0
6	12070104 3	1.15 -1	0
7	12070104 4	0.00 -1	0

The CU item stores the USGS cataloging unit (CU) number of this piece of RF3. Every arc in the coverage has the same value for CU.

The SEG item stores the number of the stream segment to which the particular arc is assigned. SEG numbers start at 1 and increment by 1 to `N' for each CU. A SEG could be all the arcs of a mainstream, the arcs of a tributary, or piece of a mainstream or tributary. SEG numbers were defined in the production of RF3:

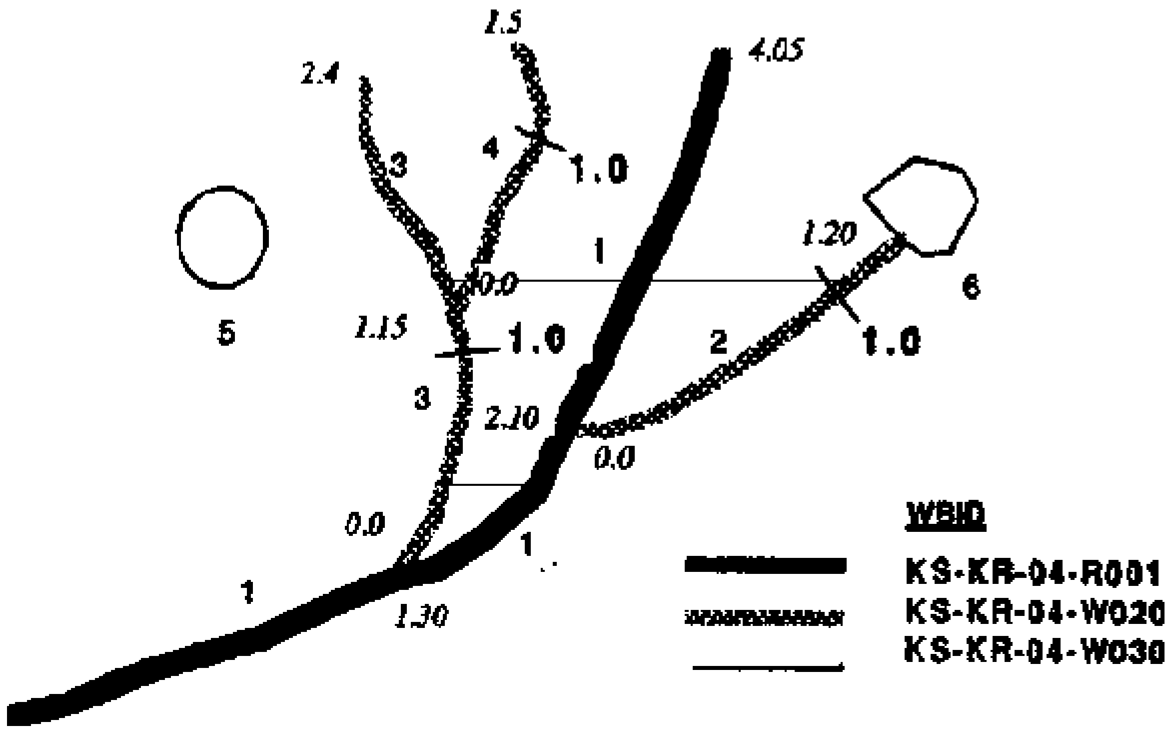

Figure 4. RF3 SEG and MI Data Elements

MI stores the marker index for each particular arc. The MI is similar to a mile posting along a stream. In reality, the MI field does not truly measure mileage along the RF3 stream network. But it does represent a method of producing a unique identifier (in combination with the CU number and the SEG number) for every reach in the United States (Figure 4).

Together CU, SEG, and MI uniquely identify every arc in RF3 nationwide. These three items are combined in the redefined item called RF3RCHID. This is a powerful scheme for consistently identifying locations along streams everywhere in the country.

Along with the AAT file, there is a second attribute file automatically created for RF3 coverages. This file is always named cover.DS3. The DS3 file stores a wealth of information about arcs in the coverage.

Some of the important fields in the DS3 file contain:

- Upstream and downstream connectivity for navigating along reaches;
- Codes to describe the type of reach (e.g. stream, lake boundary, wide river, etc.); and
- DLG major and minor attributes.

WATERBODY LOCATIONS:

Since states define waterbodies, the are the only source of information on waterbody location. South Carolina was reach indexed in 1992 and Virginia was the second state, overall, to be indexed to RF3. Virginia indexed its waterbodies using the PC Reach File program, PCRF, instead of in a GIS environment with ARC/INFO.

PCRF is a pc-based system for indexing waterbodies and locating other assessment data from WBS. PCRF stores the definitions of waterbodies (including their location) in a file that is linked to other Waterbody System database files, containing information about the assessment status and quality of the waters.

A waterbody is a set of one or more hydrologic features, such as streams, lakes, or shorelines) having similar hydrologic characteristics. Waterbodies are the basic unit states use to report water quality for Clean Water Act 305(b) requirements. Waterbodies can be defined, according to the state's assessment goals and resources, in several ways, including (Figure 5):

- All streams within a watershed,
- All lakes and ponds within a watershed, and
- Sets of streams with similar water quality conditions.

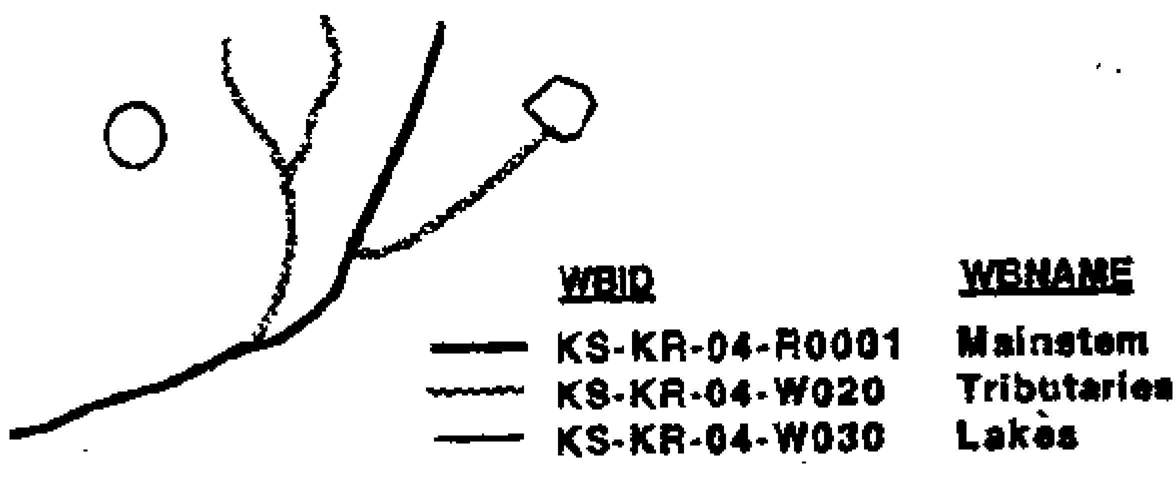

Figure 5. Potential Definitions of Waterbodies

PCRF stores locational data for a waterbody with a unique waterbody ID (WBID). This ID is used in WBS as a common field to relate the waterbody's definition and location to descriptive data about the waterbody's assessment status and quality. The two most important files used in PCRF are the SCRF1 and SCRF2 files. These two files and their significance to reach indexing are described below.

The SCRF1 file, simply lists the unique waterbodies by state:

WBID	WBNAME	WBTYPE	WBSIZE
KS-KR-04-R001	KANSAS RIVER	R	15.20
KS-KR-04-W020	LOWER WAKARUSA RIVER	R	61.60
KS-KR-04-W030	MUD CR	R	39.43
KS-KR-04-W040	CAPTAIL CR	R	15.63
.	.	.	.
.	.	.	.
.	.	.	.

The most relevant data for reach indexing in this file are the WBID, WBNAME and WBTYPE, as defined by the state. The WBID is a unique identifier for each waterbody the state has defined. The WBNAME stores a verbal description of the waterbody, and the WBTYPE defines the type of waterbody; for example, R is for river, L is for lake.

The SCRF2 file contains an explicit definition of each waterbody:

WBID	WBDIR	WBBEGIN	WBEND	RFORGFLAG
KS-KR-04-R001	U	10270104001 0.00	1027010400115.20	2
KS-KR-0R-W020	D	1027010400510.80	10270104005 0.00	2
KS-KR-04-W030	U	1027010405912.05	10270104007 8.10	3
KS-KR-04-W040	U	10270104038 0.00		3
.	.	.	.	.

Because of the complexity of defining waterbodies, more than one record may exist in this file for each waterbody. The SCRF2 file can be considered a waterbody definition *language* because it contains specific codes, attributes, and keys that can be converted into specific reaches on the RF3 data, if read properly. The WBBEGIN and WBEND fields contain explicit CU, SEG, and MI attributes to define the location of the starting point and ending point for the waterbody. The WBDIR field contains an attribute describing whether to go upstream or downstream from the WBBEGIN to the WBEND. Additionally, a blank WBEND denotes that the waterbody should include all upstream or downstream reaches (depending on the WBDIR) of the WBBEGIN reach.

Virginia used PCRF to create an SCRF2 file containing reach indexing expressions for all of their defined waterbodies. We then wrote ARC/INFO macros to process this file and expand the expressions into the set of specific arcs that are compose each waterbody. The macros will be described in more detail later.

States that have not already generated indexing expressions in PCRF must provide locations in some other way. The most basic method is for the state to supply a set of 1:100,000 USGS quad sheets which have been marked-up with locations of each waterbody. The maps can be used in conjunction with a digitizer to manually select the appropriate RF3 reaches and code them with the WBID.

The state of Ohio created a GIS database of their river reaches several years ago. The GIS coverage is representational in nature. The stream reaches are 'stick-figures' only. Generally they fall along the paths of the actual streams, but they are schematic in nature and don't show the true shape of streams. However, the is GIS layer contains the attributes of Ohio's stream reach numbering system which they use as waterbodies as well. Ohio's river reach coverage contains information on the locations of waterbodies and is being manually conflated to transfer the WBIDs to RF3. The conflation process will be covered later in this paper.

The state of Kansas had previously defined their waterbodies on RF2 - the precursor to RF3. Some of their indexes were defined by a set of RF3 SEG numbers in a CU, some were defined by the RF3 reaches in a small watershed polygon within a CU. The locations were, in effect, defined within the WBID itself.

INDEXING PROCEDURES

Procedures developed for performing waterbody indexing include automated, semi-automated, and manual systems.

Automated Indexing Procedures

Virginia performed the indexing operation using PCRF. They delivered an SCRF2 file containing indexing expressions for all of their waterbodies. AML programs were created to read the SCRF2 file and select the reaches specified by each indexing expression. The selected sets of reaches were then coded with the appropriate WBID. The macros were designed to run on one RF3 cataloging unit at a time, so the operator specified runs of up to 10 CUs at a time. The macros had to accommodate indexing expressions that included:

- Selected reaches upstream of a specified location
- Select reaches on a reach by reach basis
- Select reaches within a given polygon area
- Select the shorelines of lakes or ponds given a lat/long coordinate
- Select reach downstream from a given location

Kansas waterbodies were also indexed through an automated process. Kansas supplied an ARC/INFO coverage of small watershed polygons (sub-CU polygons) containing a watershed identifier. Their WBID contained all the other information necessary to determine the RF3 cataloging unit and the set of reaches making up each waterbody. An example of a Kansas WBID is:

KS-KR-02-W030

- KS. Refers to the state. All WBIDs in Kansas begin with KS.
- KR. The second component of the WBID is an abbreviation of the basin in which the waterbody falls. KR indicates that this waterbody is in the Kansas-Lower Republican River basin.
- 02. The third component of the WBID contains the last two digits of the 8-digit cataloging unit number. Basins are made up of several CUs, however, the last two digits of each CU in a basin are unique. Therefore, between the basin (e.g. 'KR') designation and the last two digits of the CU (e.g. '02'), the complete 8-digit CU number in which the waterbody falls is defined.
- W. This letter denotes whether the waterbody is defined by a watershed polygon (W), an RF2 SEG (R), or a lake or pond shoreline (L).
- 030. The number of the polygon containing the reaches for the waterbody in the watershed coverage.

The completed macros could index the entire state in a single run provided that all the WBIDs were contained in single file.

In all cases, Kansas has indexed to RF2 reaches, therefore, only RF3 reaches originally created in RF2 production are coded with a WBID.

Manual Indexing Procedures

Since Ohio already has a coverage of river reach codes, WBIDs from this coverage had to be transferred to the RF3 reaches they represent. A manual conflation process was used. The operator displayed a cataloging unit of RF3 along with the Ohio river reach system for the same area. In a simple process of 'pointing and clicking' the operator first selected an Ohio river reach arc, then the RF3 arcs that seemed to coincide. As each RF3 arc was selected it was coded with the WBID of the previously selected Ohio river reach arc.

Other states which have no means of describing waterbodies in electronic files may have to resort to marking up paper maps to show waterbody locations. These maps can then be used in a manual process of selecting RF3 reach and coding them with WBIDs either in ARC/INFO or in PCRF.

USING THE ROUTE SYSTEM DATA MODEL TO STORE WATERBODIES

Because Waterbodies can be defined as noncontiguous sets of arcs and portions of arcs, a robust linear database model must be used to model these entities. ARC/INFO's route system data model seems well suited for this application. The routes system data model allows one to group any set of arcs or portions of arcs into routes. Each route is managed as a feature in itself. Attributes of waterbodies are stored in a Route Attribute Table (RAT) and relate to all the arcs defined as the waterbody (Figure 6). This diagram will help illustrate the route system model:

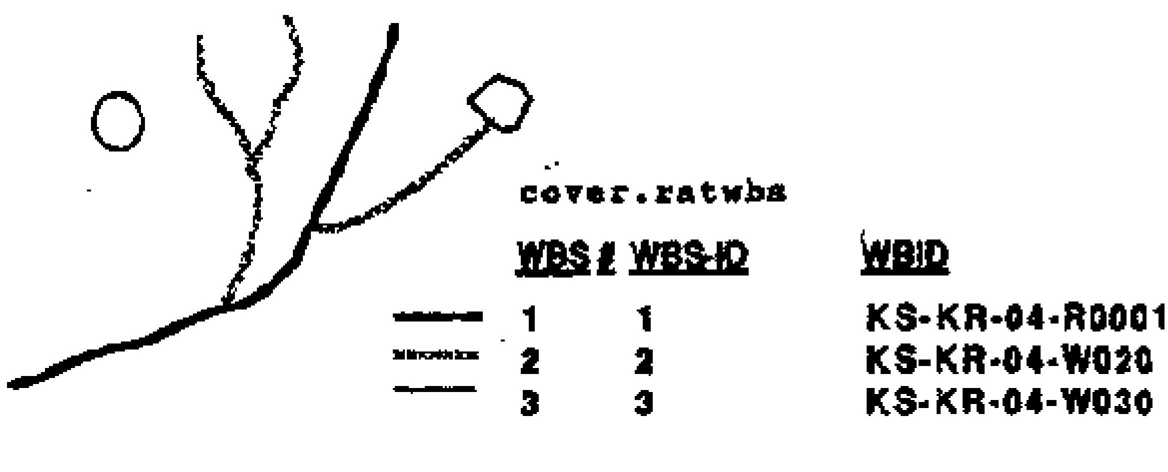

Figure 6. The Route Attribute Table Containing Waterbody Data

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Each route is made up of one or more arcs or sections of arcs. ARC/INFO manages the relationship between arcs and routes in the section (SEC) table. The SEC is an INFO table with the following structure:

ROUTELINK# • The route upon which the section falls
ARCLINK# • The arc upon which the section falls

F-MEAS	• The measurement value at the beginning of the section
T-MEAS	• The measurement value at the end of the section
F-POS	• The percent of the distance along the arc at which the section begins
T-POS	• The percent of the distance along the arc at which the section ends
SEC#	• The internal identifier of the section
SEC-ID	• The user identifier of the section

The sections that would make up the above routes would appear as follows:

ROUTELINK#	ARCLINK#	F-MEAS	T-MEAS	F-POS	T-POS	SEC#	SEC-ID
1	1	0	1.30	0	100	1	1
1	2	1.30	2.10	0	100	2	2
1	3	2.10	4.05	0	100	3	3
2	4	0	1.20	0	100	4	4
3	5	0	1.15	0	100	5	5
3	6	1.15	2.4	0	100	6	6
3	7	0	2.5	0	100	7	7
.	.	.	.	.	.	.	.

Representing Waterbodies as Routes

There are several ways of grouping sets of arcs into discrete routes in ARC/INFO. One can use ARCEDIT to select a set of arcs to group them into a route, or one can use ARCSECTION or MEASUREROUTE in ARC to group arcs into routes. The method described here uses the MEASUREROUTE command. This requires that there is an attribute on the AAT or a related table which contains the identifier of the route to which an arc should be assigned. In the application employed by the authors, the SCRF2 file was converted into an INFO table containing, for each arc in the coverage, the RF3RCHID of the arc and the WBID to which the arc should be assigned. The WBID item will be used to group arcs into routes. There will be one route for each unique WBID. The table used in MEASURE is illustrated below. This table is related to the AAT of the RF3 coverage by the RF3RCHID:

$RECNO	RF3RCHID	WBID
1	10270104 1 0.00	KS-KR-04-R0001
2	10270104 1 1.30	KS-KR-04-R0001
3	10270104 1 2.10	KS-KR-04-R0001
4	10270104 2 0.00	KS-KR-04-W020
5	10270104 3 0.00	KS-KR-04-W020
6	10270104 3 1.15	KS-KR-04-W020
7	10270104 4 0.00	KS-KR-04-W020
8	10270104 5 0.00	KS-KR-04-W030
9	10270104 6 0.00	KS-KR-04-W030

A route attribute table (RAT) is automatically created for the coverage, which now can be related to other WBS assessment files for display and query. Figure 4 illustrates what the route attribute table

(RAT) would look like. The important characteristic of the file is that there is only one record for each waterbody which will simplify the display and query of waterbodies based on water quality data.

Using EVENTS for Sub-Waterbody Attributes

Waterbodies, as defined by states, are often a gross aggregation of the water in an area. States often have more specific data about particular stretches of streams within a waterbody. A system is needed in order to query and display data at the sub-waterbody level. ARC/INFO's Dynamic Segmentation tools and event tables are useful in this application. When waterbodies have been previously defined and reporting methods setup based on those waterbodies, it is cumbersome to redefine them. Event tables can be used to keep these waterbody definitions and still be able to store, manage, and track data at the sub-watershed level. Event tables are simple INFO files which relate to route systems on coverages. This concept and data structure can be implemented in conjunction with the predefined waterbody system. We have already seen how a route system called WBS is created in RF3 to group arcs into waterbody routes. This works quite well when displaying waterbodies and querying their attributes. A route system based on the WBID cannot, however, be used as an underlying base for subwaterbody events because the measures used to create the WBS route system are not unique for a particular route. For example, in the following route, there are three locations defined as being on WBID KS-KR-04-W020 and having measure 1.0.

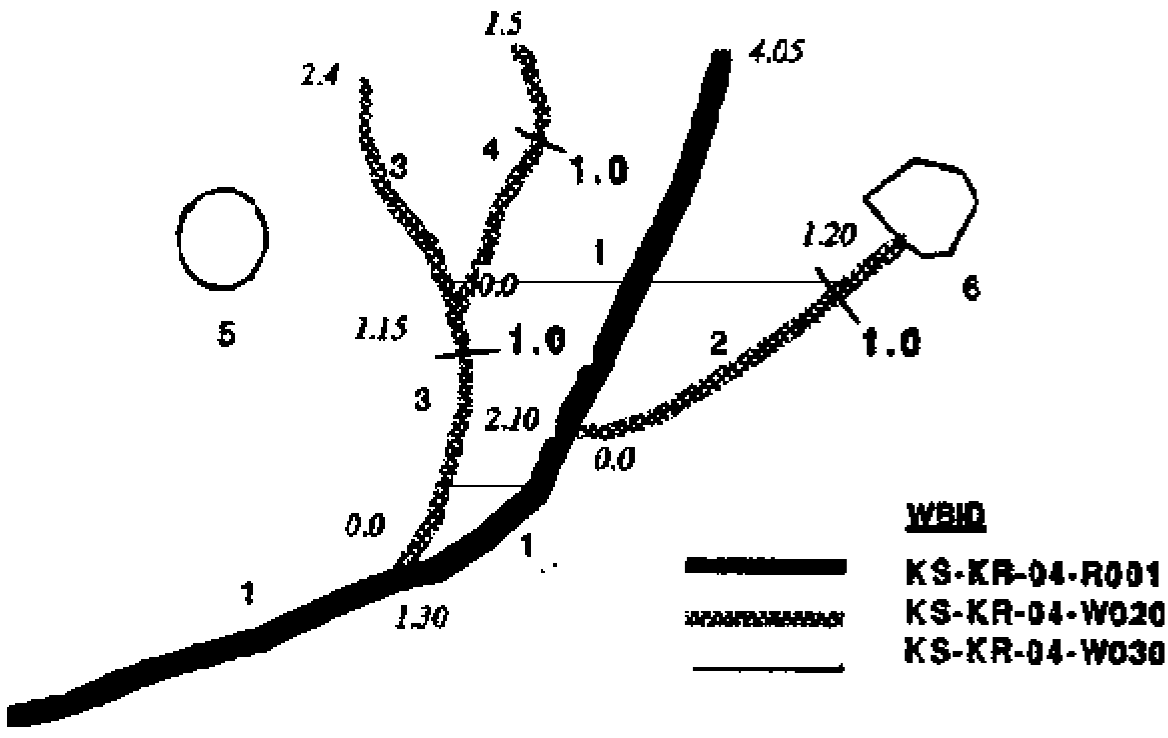

Figure 7. Measurements Along SEGs.

The mileage measurements along SEGS, however, are always unique (see Figure 3). In order to use events, therefore, it is necessary to create a second route system based on the RF3 SEG attribute, which provides a unique code for each CU.

The ARCSECTION command, instead of the MEASUREROUTE command, is used to create the SEG route system. This is because the measurement items (MI on the AAT and UPMI on the DS3) already store the summed measures along particular SEGs. The resulting RAT table will contain the following:

SEG-ID	SEG#	SEG
1	1	1
2	2	2
3	3	3

Since the name of the route system is SEG, the SEG# and SEG-ID are the names of the internal- and user-ids. The SEG item contains the actual SEG number in the RF3 coverage. Because each RF3 CU coverage has SEG numbers starting at 1 and incrementing by 1, the SEG item looks much like the SEG-ID and SEG#.

Event tables contain a key item, the WBID or SEG to relate them to the appropriate route system, They also contain locational information on where the events are located on the route (either WBID, to indicate the waterbody on the WBS route, or SEG to identify the route in the SEG route system). Use support, causes, and sources can then be related in separate event tables as linear events. FROM and TO store the starting and ending measures for each event. Use of event tables allows us to apply many useful cartographic effects (e.g., hatching, offsets, text, and strip maps). Events can be queried both in INFO and graphically. Event data can be used to produce overlays of two or more event tables.

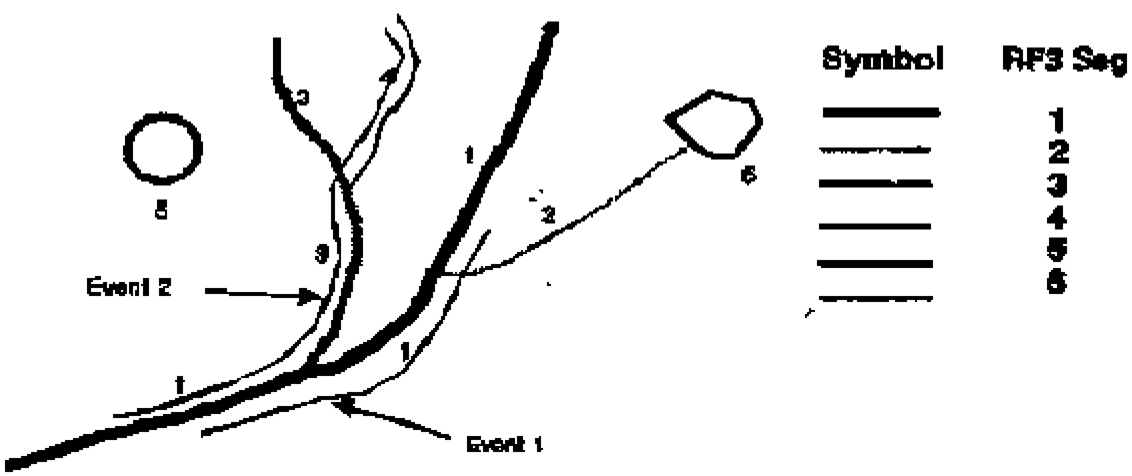

Figure 8. Events Located on RF3 Data.

SEG	FROM	TO	WBID	USE	USE SUPPORT
1	0.80	1.30	KS-KR-04-R0001	21	Fully
1	1.30	2.10	KS-KR-04-R0001	21	Partial
1	2.10	2.31	KS-KR-04-R0001	21	Not Supported
1	0.50	1.30	KS-KR-04-R0001	40	Threatened
3	0.00	1.15	KS-KR-04-W030	21	Fully
4	0.00	2.5	KS-KR-04-W040	40	Not Supported

Use support information can be displayed in an event table similar to that shown above. WBS users can update their event tables, using RF3 maps supplied by EPA without having proficiency in ArcInfo. It is expected that ArcView2 will support events and route systems. This will give users powerful tools for spatial query of their assessment data. Event tables would also be developed to display and query data on the causes and sources of use impairment. These events can be offset and displayed to show the areas of interaction. More permanently, line on line overlays can be prepared to show intersections and unions.

An alternative approach is to use an EVENT-ID as a unique identifier for each event. The SEG field stores the number of the route (SEG) upon which the event occurs. FROM and TO store the beginning and end measure, respectively, along the route upon which the event occurs. WBID contains the identifier of the waterbody upon which the event occurs. An event can occur within a single SEG, across two or more SEGs, within a single waterbody, or across two or more waterbodies.

EVENT-ID	SEG	FROM	TO	WBID
1	1	0.80	1.30	KS-KR-04-R0001
1	1	1.30	2.10	KS-KR-04-R0001
2	4	0.00	2.5	KS-KR-04-W040
.	.	.	.	.

Additional attribute tables can be created to store descriptive attributes for each event. These tables would be similar to the SCRF5 and SCRF6 files except that instead of using the WBID to relate to a *waterbody*, an field called 'EVENT-ID' would be included to link the use, cause, and source data to a particular *event*.

EVENT-ID	ASCAUSE	ASSOURC
1	900	1200
1	-9	1100
1	0500	1100
2	1200	9000
2	0900	8100

Both approaches offer some advantages. In either case they allow us to map our water quality assessment data and communicate it in a way that is meaningful and useful.

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